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-	212	transducer and (piezoresistive adj sensor) and circuit	USPAT; US-PGPUB; EPO; DERWENT	2003/08/20 14:46
-	121	(pressure adj transducer) and (piezoresistive adj sensor) and circuit	USPAT; US-PGPUB; EPO; DERWENT	2003/08/20 14:46
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-	7	128/$.ccls. and amplifier and (voltage near clamping)	USPAT; US-PGPUB; EPO; DERWENT	2003/08/20 17:53

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United States Patent [19]

Phillips

[11] **Patent Number: 5,438,980**

[45] **Date of Patent: Aug. 8, 1995**

[54] **INHALATION/EXHALATION RESPIRATORY PHASE DETECTION CIRCUIT**

[75] Inventor: **Steven L. Phillips**, Olathe, Kans.

[73] Assignee: **Puritan-Bennett Corporation**, Lenexa, Kans.

[21] Appl. No.: **3,129**

[22] Filed: **Jan. 12, 1993**

[51] **Int. Cl.⁶** **A61M 16/00**

[52] **U.S. Cl.** **128/204.23**; 128/204.21

[58] **Field of Search** 128/204.18, 204.21, 128/204.23, 207.18

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Assistant Examiner—Aaron J. Lewis
Attorney, Agent, or Firm—Fulwider Patton Lee & Utecht

[57] **ABSTRACT**

An apparatus (**10**) for controlling the pressure of a respiratory gas delivered to a patient includes a phase detection circuit (**24**) for determining the inhalation and exhalation phases of the patient's respiratory cycle. More particularly, a flow signal representative of the respiratory flow is compared to second signal, offset in time and scaled in magnitude relative to the flow signal, in order to determine the transition from one phase to the next.

27 Claims, 5 Drawing Sheets

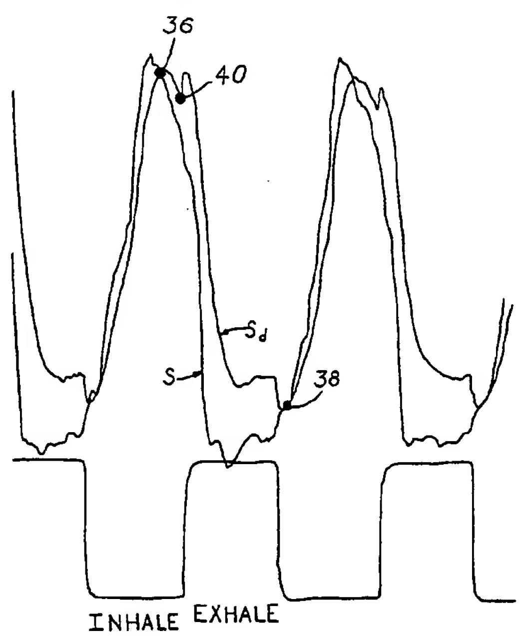
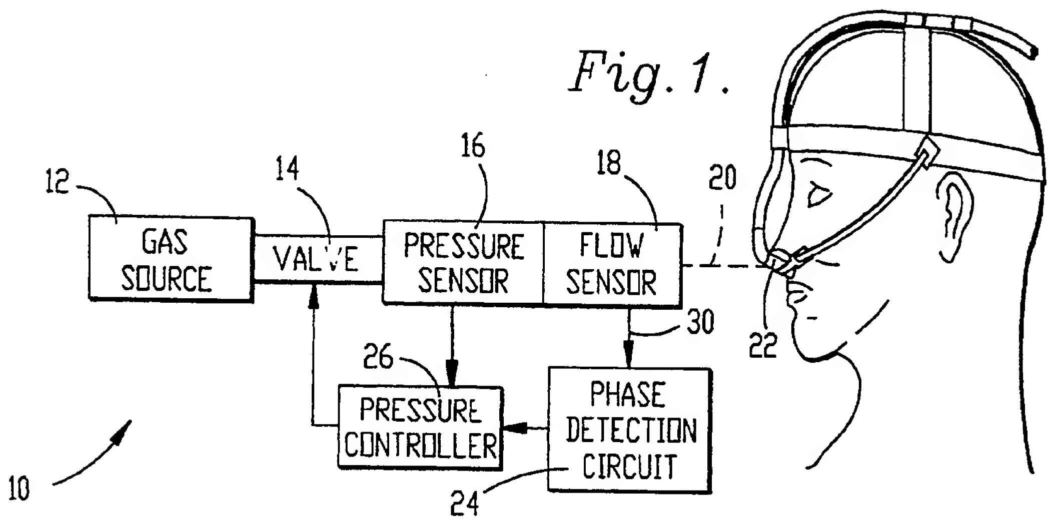


Fig. 1.


12
GAS SOURCE
14
VALVE
16
PRESSURE SENSOR
18
FLOW SENSOR
20
22
30
26
PRESSURE CONTROLLER
PHASE DETECTION CIRCUIT
24
10

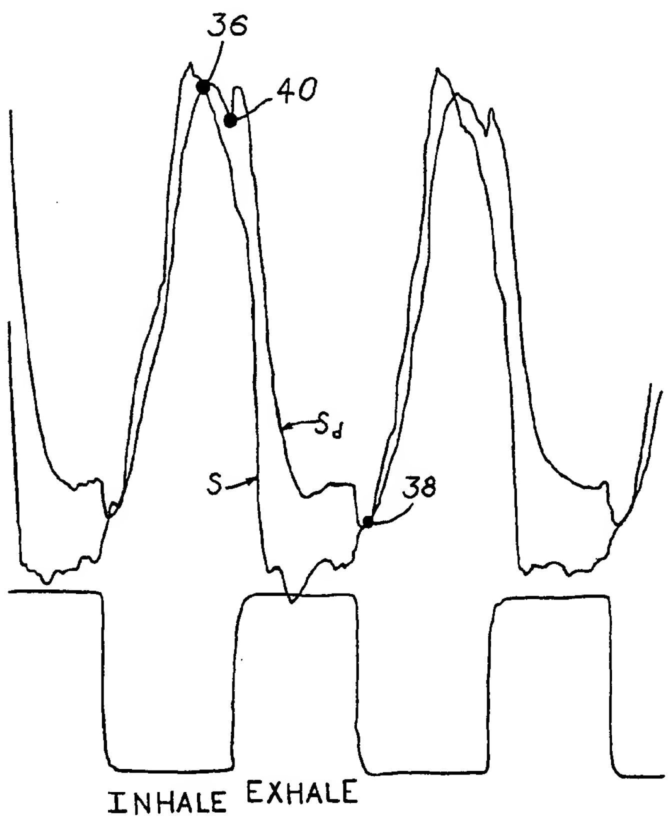
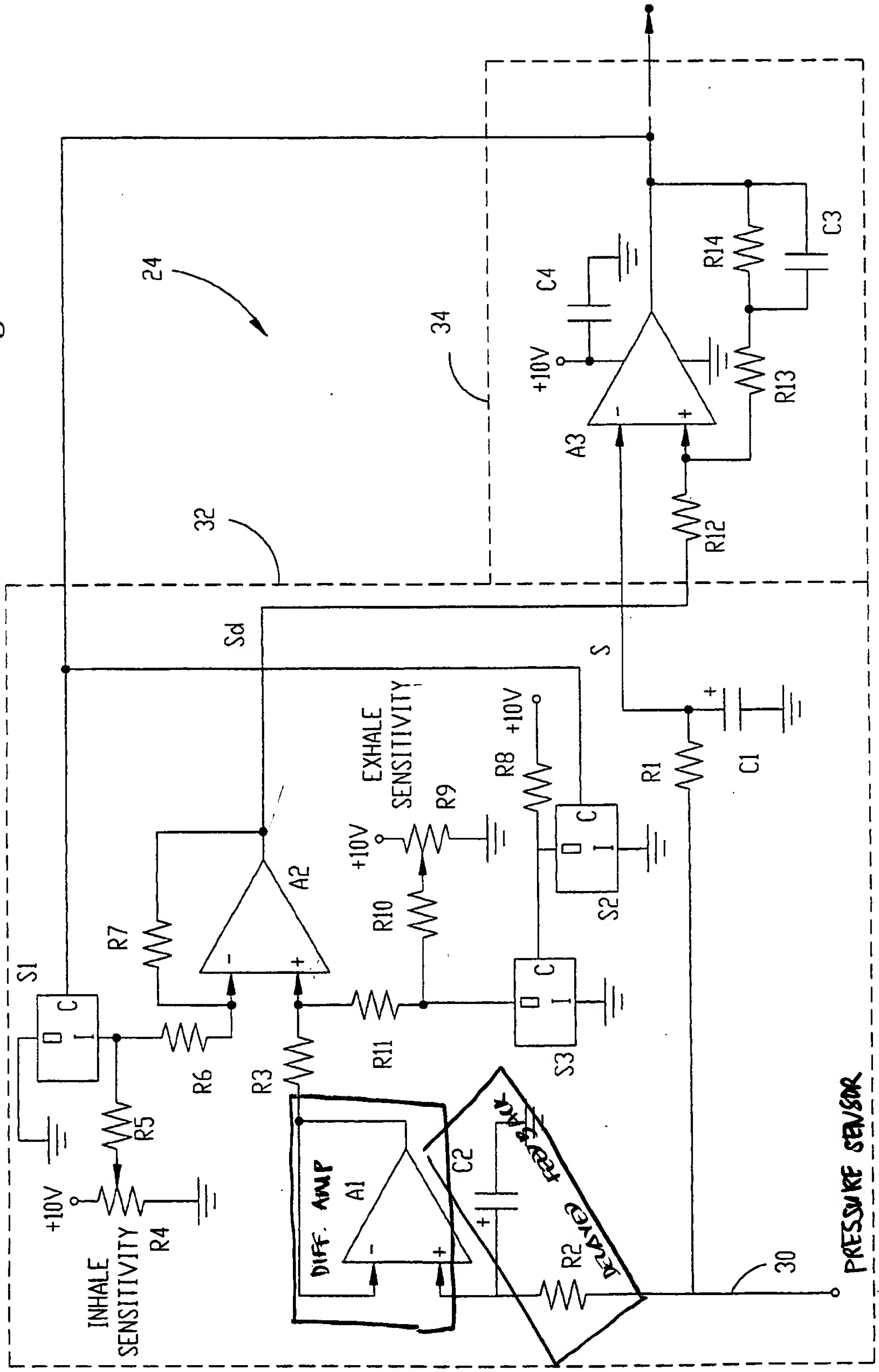

36
40
S_d
S
38
INHALE
EXHALE

Fig. 3.

Fig. 2.


24
34
32
+10V
C4
R14
C3
R13
A3
R12
Sd
S
EXHALE SENSITIVITY
+10V
R8
R9
R10
A2
R7
S1
C1
R1
S2
S3
R11
R6
R3
R5
+10V
INHALE SENSITIVITY
R4
DIFF. AMP
A1
C2
FEED BACK
DELAYED
R2
30
PRESSURE SENSOR

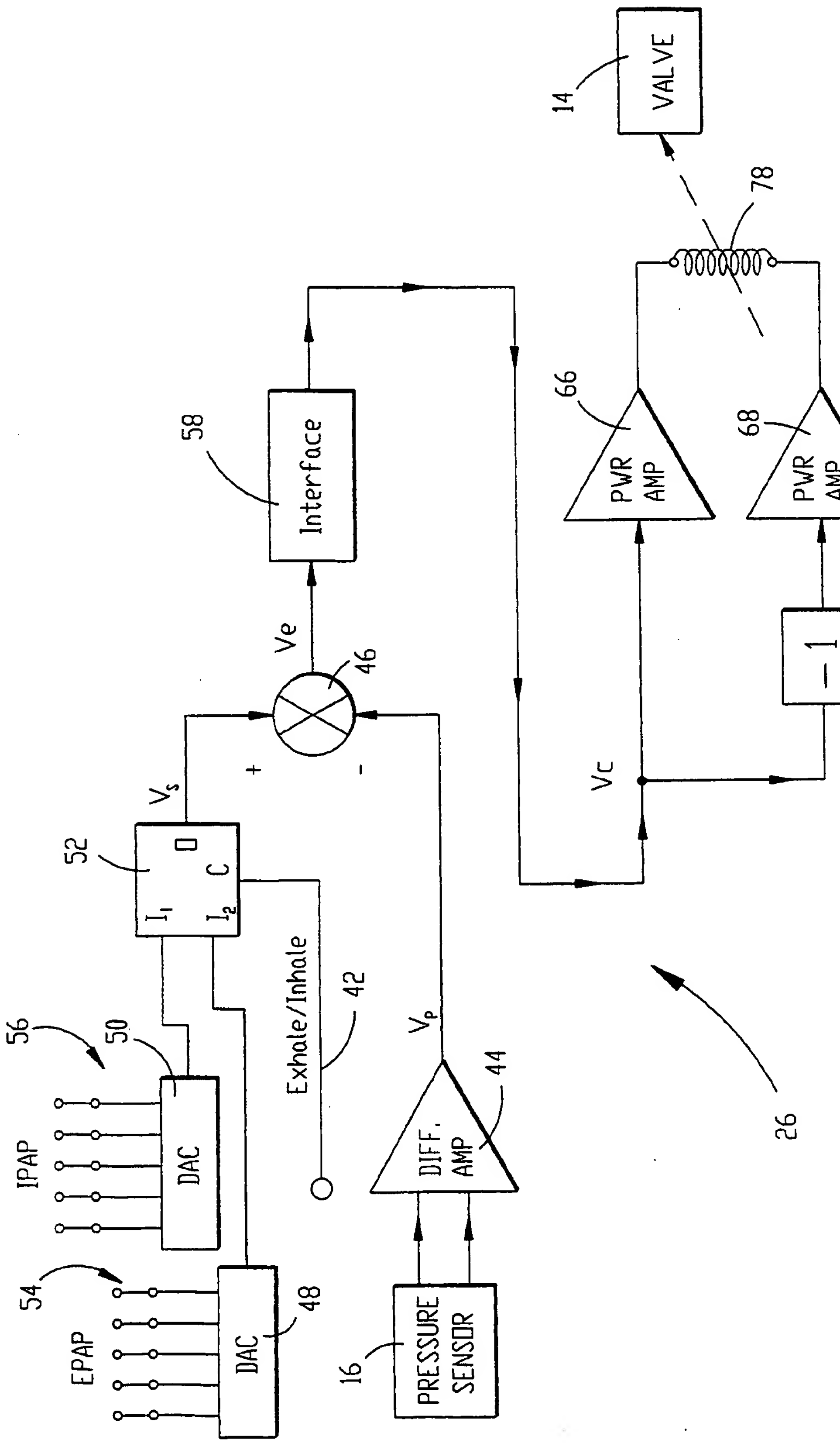

VALVE
14
78
Interface
58
66
PWR AMP
68
PWR AMP
Ve
46
− 1
Vs
+
-
52
I1
I2
D
C
Vc
56
50
IPAP
DAC
Exhale/Inhale
42
Vp
44
DIFF. AMP
26
54
EPAP
DAC
48
16
PRESSURE SENSOR

Fig. 4.

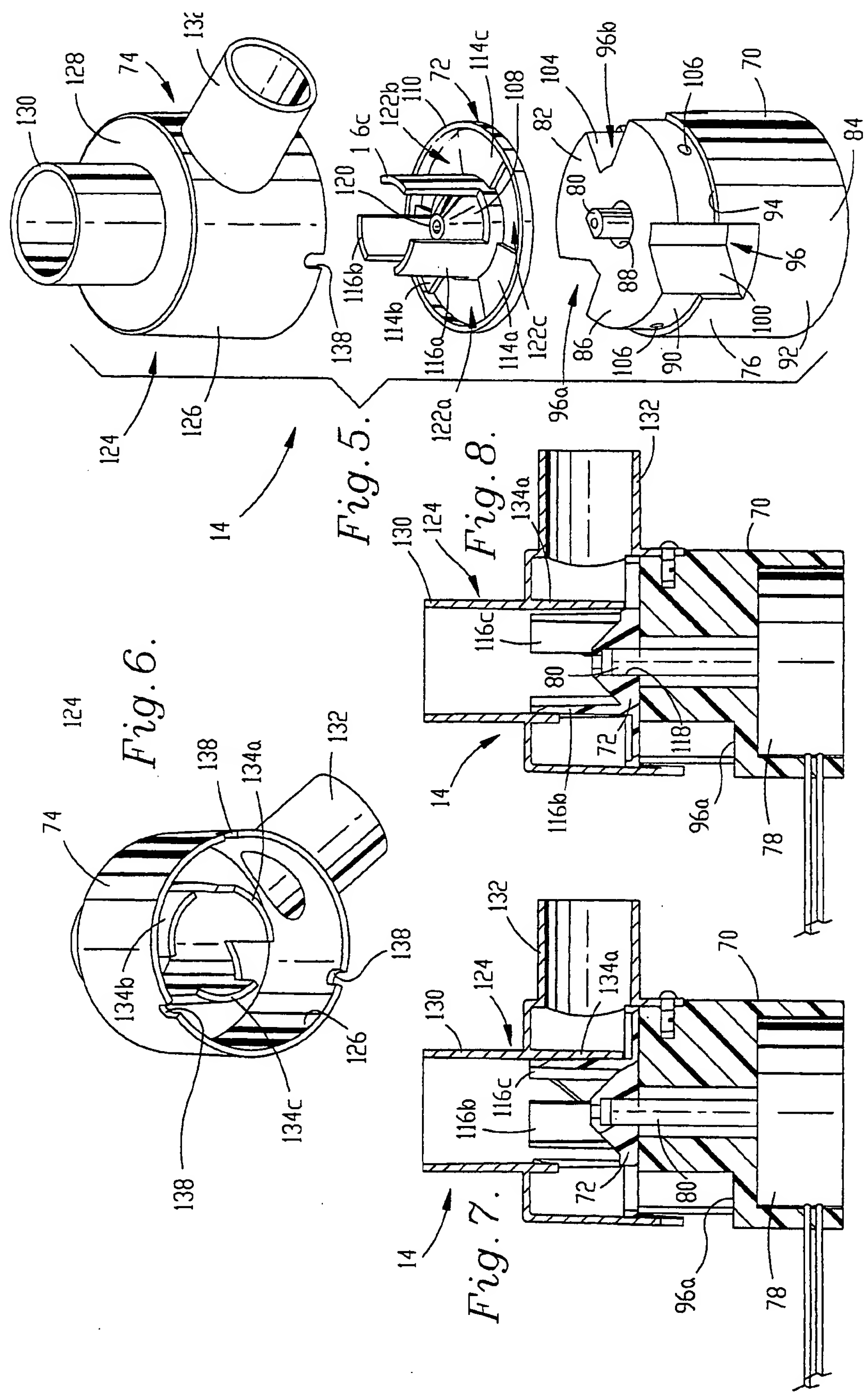


Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

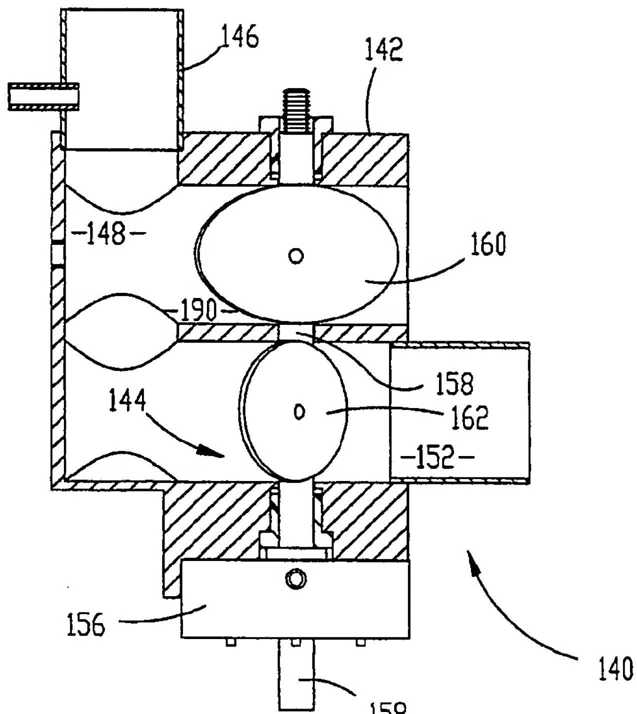


Fig. 11.

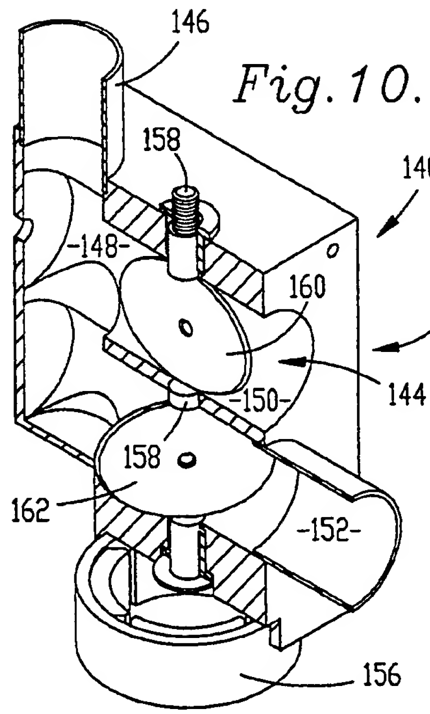


Fig. 10.

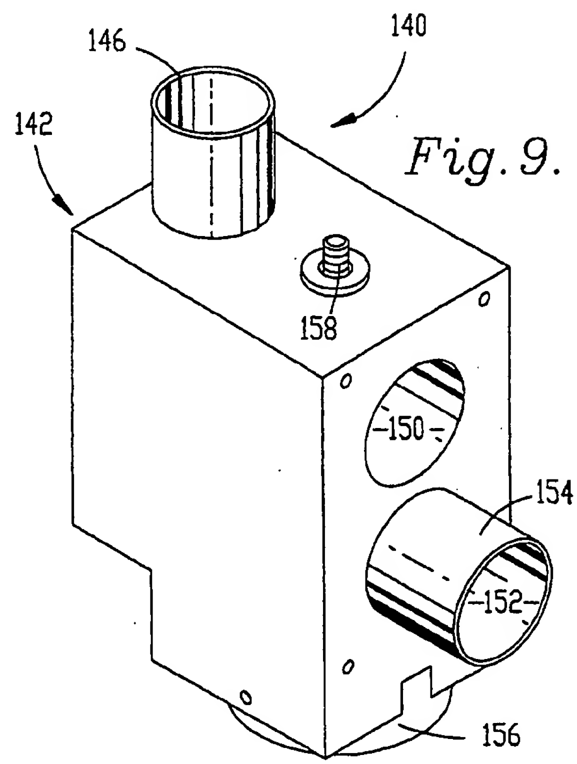


Fig. 9.

INHALATION/EXHALATION RESPIRATORY PHASE DETECTION CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is concerned with an apparatus for controlling the pressure of a respiratory gas delivered to a patient. More particularly, the preferred apparatus includes a trigger circuit for determining the inhalation and exhalation phases of the patient's respiratory cycle.

2. Description of the Prior Art

Obstructive sleep apnea is a sleep disorder characterized by relaxation of the airway including the genioglossus throat muscle during sleep. When this occurs, the relaxed muscle can partially or completely block the patient's airway. Partial blockage can result in snoring or hypopnea. Complete blockage results in obstructive sleep apnea.

When complete blockage occurs, the patient's inhalation efforts do not result in the intake of air and the patient becomes oxygen deprived. In reaction the patient begins to awaken. Upon reaching a nearly awakened state, the genioglossus muscle resumes normal tension which clears the airway and allows inhalation to occur. The patient then falls back into a deeper sleep whereupon the genioglossus muscle again relaxes and the apneic cycle repeats. In consequence, the patient does not achieve a fully relaxed deep sleep session because of the repetitive arousal to a nearly awakened state. People with obstructive sleep apnea are continually tired even after an apparently normal night's sleep.

In order to treat obstructive sleep apnea, a system of continuous positive airway pressure (CPAP) has been devised in which a prescribed level of positive airway pressure is continuously imposed on the patient's airway. The presence of such positive pressure provides a pressure splint to the airway in order to offset the negative inspiratory pressure that can draw the relaxed airway tissues into an occlusive state. The most desired device for achieving a positive airway connection is the use of a nasal pillow such as that disclosed in U.S. Pat. No. 4,782,832, hereby incorporated by reference. The nasal pillow seals with the patient's nares and imposes the positive airway pressure by way of the nasal passages. The nasal pillow also includes a small vent for continuously exhausting a small amount of air in order to prevent carbon dioxide and moisture accumulation.

In the CPAP system, the patient must exhale against the prescribed positive pressure. This can result in patient discomfort, especially at the higher pressure levels. Because of this problem, the so-called bi-level positive airway pressure (BiPAP) system has been developed in which the pressure is lowered during the exhalation phase of the respiratory cycle. Practical implementation of the BiPAP system has met with only marginal success because of the difficulty in accurately and reliably detecting the occurrence of the exhalation and inhalation phases of the respiratory cycle. Respiratory phase detection has been a problem because the continual air exhaust at the nasal pillow, and other system leaks, results in a net positive air flow to the patient. Thus, phase transition cannot be determined merely on the basis of a change in the direction of air flow.

SUMMARY OF THE INVENTION

The apparatus of the present invention solves the prior art problems discussed above and provides a distinct advance in the state of the art. More particularly, the apparatus hereof reliably determines inhalation and exhalation phases in the respiratory cycle in order to control respiratory gas pressure in response.

The preferred embodiment of the invention hereof includes a gas supply for supplying a respiratory gas under pressure from a source thereof to a patient, a phase detection circuit for detecting the inhalation and exhalation respiratory phases, and a pressure controller for controlling the pressure delivered to the patient in a predetermined manner correlated with the respiratory phases.

The preferred phase detection circuit produces first and second signals representative of respiratory gas flow with these signals being time displaced relative to one another and scaled in magnitude. With this configuration, the signals present different gains and voltage offsets relative to one another during respective phases of the respiratory cycle. These two signals are compared to determine transitions, which correlate with transitions from one respiratory phase to another. With reliable phase detection, the gas pressure delivered to the patient is controlled in accordance with the phases.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of the preferred apparatus for facilitating the respiration of a patient;

FIG. **2** is an electrical schematic of the preferred phase detection circuit of the apparatus of FIG. **1**;

FIG. **3** is a graph illustrating the flow and offset signals of the detection circuit of FIG. **2** and illustrating patient inhalation and exhalation phases;

FIG. **4** is an electrical block diagram illustrating the preferred pressure controller of FIG. **1**;

FIG. **5** is an exploded perspective view of the major components of the preferred valve of FIG. **1**;

FIG. **6** is a lower perspective view of the inlet/outlet housing of the valve of FIG. **5**;

FIG. **7** is a partial sectional view of the assembled valve of FIG. **5** illustrating the shiftable components in a first position;

FIG. **8** is a partial sectional view of the assembled valve of FIG. **5** illustrating the shiftable components in a second position;

FIG. **9** is a perspective view of a second embodiment of the valve of FIG. **1**;

FIG. **10** is a cut-away perspective view of the valve of FIG. **9**; and

FIG. **11** is a sectional view of the valve of FIG. **9**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to FIG. **1**, apparatus **10** includes gas source **12**, control valve **14**, pressure sensor **16** and flow sensor **18** coupled with a so-called ADAM circuit available from Puritan Bennett Corp. of Lenexa, Kans., which includes pneumatic hose **20** and nasal pillow **22**. Apparatus **10** further includes phase detection circuit **24** and pressure controller **26**. In the preferred embodiment, components **12–18** and **24–28** are enclosed in a single housing to which the ADAM circuit is coupled.

Gas source is preferably a variable speed blower operable to produce 120 liters per minute at 30 cm. water pressure. The preferred pressure sensor **16** is

available from Sensym Company as model number SCX01. Flow sensor 18 is preferably model AWM2300 available from Microswitch Corp., transducer operable for producing an electrical signal on line 30 representative of the air flow therethrough and thereby representative of the air flow delivered to the patient.

FIG. 2 is an electrical schematic of phase detection circuit 24 which includes signal production circuit 32 and signal processing circuit 34. Signal production circuit 32 receives the flow signal from flow sensor 18 by way of line 30. This signal is filtered for noise and other transients by resistor R1 (22K) and capacitor C1 (1 uF) connected as shown in FIG. 2 and delivered as signal "S" to signal processing circuit 34.

Signal production circuit 32 also transforms the flow sensor signal into an offset signal "Sd" which is delayed in time and scaled in magnitude relative to signal S. Initially the flow sensor signal is time delayed by 200 milliseconds using resistor R2 (100K) and capacitor C2 (2.2 uF) interconnected as shown. The relative time delay between time signals S and Sd is illustrated by the graphs in FIG. 3.

The time delayed signal is then delivered to the positive input terminal of amplifier A1 (type 358A) with the output therefrom connected as feedback to a negative input terminal. The output of amplifier A1 is also connected to output resistor R3 (221K). Amplifier A1 functions as a voltage follower to provide a high impedance input to the flow signal.

The conditioned time delay signal is then processed to scale the magnitude thereof so that signal Sd presents lower amplitude than signal S during the inhalation phase, and so that signal Sd presents a higher amplitude than signal S during the exhalation phase as illustrated in FIG. 3. To accomplish this, the gain of the signal is changed independently for the inhalation and exhalation portions of the signal and a variable offset is added by the sensitivity potentiometers R4 and R9.

As discussed further hereinbelow, the output from phase detection circuit 24 produces a logic high output during exhalation and a logic low during inhalation. These outputs are also provided as feedback to signal production circuit 32, specifically to control terminal C of CMOS inhalation switch S1 and to control terminal C of CMOS switch S2. These CMOS switches are type 4066B and operate so that when a logic high input is provided to terminal C, the switch is "on," that is, connection is made between terminals "I and "O" thereof. When terminal C is low, the connection between terminals I and O is open.

During inhalation, terminal C of switch S1 is low and the switch is off. Voltage is then supplied to the negative input terminal of amplifier A2 (type 358A) by way of inhale sensitivity potentiometer R4 (500 Ohms full-scale), resistor R5 (10K) and resistor R6 (221K). Resistor R7 (221K) interconnects the output of amplifier A2 with the negative input terminal thereof. The level of the voltage delivered to negative input terminal of amplifier A2 determines the amplitude scaling of the delayed flow sensor signal delivered to the positive input terminal. More specifically, potentiometer R4 is adjusted to provide the desired offset of output signal Sd relative to signal S during inhalation.

Also during inhalation, the logic low signal is delivered to terminal C of switch S2, which turns this switch off. In turn, a logic high signal is imposed on terminal C of CMOS switch S3 by way of resistor R8 (10K). This turns on switch S3 which imposes ground potential on the voltage output from potentiometer R9 and resistor R10 and thereby disables the exhale sensitivity portion of the circuit.

During exhalation, a logic high signal is delivered to terminal C of switch S1 which then turns on and imposes ground potential on the voltage output from potentiometer R4 and resistor R5 in order to disable the inhalation sensitivity portion of the circuit. The logic high exhalation signal also turns on switch S2 which imposes ground potential on the voltage output from resistor R8. In turn, switch S3 turns off. This allows exhale sensitivity voltage to be delivered to the positive input terminal of amplifier A2 by way of exhale sensitivity potentiometer R9 (500 Ohms full scale), resistor R10 (10K) and resistor R11 (221K). Potentiometer R9 is adjusted to provide the desired offset of signal Sd relative to signal S during inhalation.

As illustrated in the graph of FIG. 3, signal production circuit 32 produces signals S and Sd so that the voltage level of signal Sd is less than that of signal S during inhalation. Conversely, the voltage level of signal S is less than that of signal Sd during exhalation.

Signal processing circuit 34 receives signals S and Sd and compares these signals to determine the occurrence of the inhalation and exhalation phases of the respiratory cycle. Specifically, signal S is received at the negative input terminal of comparator A3 (type 358A) and signal Sd is received at the positive input terminal thereof by way of resistor R12 (100K). When the voltage level of signal S is greater than that of signal Sd, the output from comparator A3 is logic low and inhalation is indicated thereby. When the voltage level of signal Sd is the greater of the two, comparator A3 output goes high and exhalation is indicated.

Resistor R13 (100K), resistor R14 (10 m), and capacitor C3 (2.2 uF) are interconnected with comparator A3 as illustrated in FIG. 2 and provide a signal blanking interval after a transition in the output of comparator A3. More particularly, resistor R13 and capacitor C3 provide increased voltage hysteresis in the delivery of feedback from the output to the positive input terminal of comparator A3 in order to eliminate false triggering due to transients, noise or the like. Capacitor C4 (100 nF) provides input smoothing for the supply voltage delivered to comparator A3.

An inspection of the graphs of signals S and Sd in FIG. 3 illustrates crossover points 36 and 38, and artifact 40 at the inhalation peak in signal Sd. Crossover points 36,38 are determined by the time delay imposed by resistor R2 and capacitor C2, by the amplitude scaling, and by the offset voltages which can be adjusted by potentiometers R4 and R9 for the respective phases. Artifact 40 corresponds to the phase change from inhalation and exhalation, and occurs because of the transition of signal production circuit 32 between the inhalation and exhalation offset modes. The time delay from crossover 36 to artifact 40 corresponds to the blanking interval determined by the hysteresis of comparator A3 as set by resistors R12, R13 and R14. Phase detection circuit 24 provides an output on line 42 representative of the inhalation and exhalation phases of the patient. More particularly, circuit 24 provides a logic high output at +10 VDC during exhalation and a logic low output at 0 volts during inhalation.

FIG. 4 is an electrical block diagram illustrating pressure controller 26, control valve 14 and pressure sensor 16. In general, controller 26 receives signals from phase detection circuit 24 and pressure sensor 16 and, in re-

sponse, operates valve 14 to maintain the respective inhalation and exhalation pressures delivered to the patient.

Pressure sensor 16 provides a pair of differential voltage signals to the corresponding inputs of differential amplifier 44 that responds by providing a voltage output (Vp) to error detector 46 representative of the pressure being delivered to the patient. Conventional error detector 46 compares the pressure signal Vp with a set point pressure signal Vs in order to produce error signal Ve.

Set point signal Vs is produced by digital-to-analog converter (DAC) 48, DAC 50 and CMOS switch 52. DAC 48 receives a digital input representative of the desired exhalation positive air pressure (EPAP) by way of a set of five DIP switches 54, and converts the digital output to a representative analog signal delivered to terminal I2 of switch 52. Similarly, DAC 50 receives its digital input for inhalation positive air pressure (IPAP) from a set of five DIP switches 56, and delivers its analog output to terminal I1 of switch 52. Control terminal C is connected to line 42 and receives the inhalation and exhalation signals from phase detection circuit 24. During exhalation, the +10 VDC signal received at terminal C activates switch 52 to provide the EPAP voltage at terminal I2 as the output Vs. During inhalation, the logic low signal at terminal C causes switch 52 to provide the IPAP voltage at terminal I1 as the output Vs.

Error signal Ve is provided to interface 58 which is a conventional interface circuit designed to transform error signal Ve into a signal Vc compatible with valve 14 according to the specifications supplied by the manufacturer. Signal Vc is delivered to power amplifier 66 and is inverted as a corresponding input to power amplifier 68. The net result is a differential voltage output from amplifiers 66 and 68 which is delivered to the terminals of the valve motor of control valve 14, as explained further hereinbelow.

FIGS. 5–8 illustrate preferred control valve 14, which includes valve base 70, shiftable valve element 72 and valve element cover 74. Valve base 70 includes housing 76 and valve motor 78 having motor shaft 80 with locking hole 81 defined in the end thereof.

Housing 76 is preferably composed of synthetic resin material having a generally cylindrical configuration and presents upper and lower sections 82 and 84. Upper section 82 includes upper face 86 having centrally defined opening 88 for receiving motor shaft 80, Which extends upwardly therethrough. Sidewalls 90 of upper section 82 present a slightly smaller diameter than sidewalls 92 of lower section 84 and thereby define shelf 94 for supporting valve cover 74. Housing 76 also includes three, outwardly and upwardly opening recesses 96*a*, 96*b* and 96*c* presenting a generally trapezoidal configuration in cross section. Each recess is defined by lower wall 98, and side walls 100, 102 and 104. Additionally, upper section sidewalls 90 include three outwardly locking bosses 106 located midway between adjacent recesses 96*a–c*.

Integral valve element 72 includes frusto-conically shaped hub 108, support ring 110, three, pie-shaped, equally spaced, support bodies 114*a*, 114*b* and 114*c* interconnecting hub 108 and support ring 110, and three, rectangularly shaped valve fingers 116*a*, 116*b* and 116*c* equally spaced about the periphery of hub 108 and extending upwardly therefrom. Hub 108 includes hole 118 defined in the lower surface thereof for receiving motor shaft 80. Additionally, hub 108 includes aperture 120 centrally defined through the upper surface thereof for receiving a locking screw therethrough which is further received in motor shaft locking hole 81 for securing element 72 to shaft 80. Hub 108, ring 110 and support bodies 114*a–c* define three, equally spaced, exhaust ports 122*a*, 122*b* and 122*c* presenting a shape congruent with recesses 96*a–c* and configured for registration therewith.

Valve element cover 74 includes inverted cup shaped member 124, presenting sidewall 126 and top wall 128, and further includes inlet tube 130, outlet tube 132 and valve fingers 134*a*, 134*b* and 134*c*. Inlet tube 130 is coaxial with cup shaped member 124 at top wall 128 while outlet tube 132 extends outwardly from sidewall 126. Equally spaced fingers 134*a–c* depend downwardly from inner surface 136 of top wall 128 and are configured intercalate with fingers 116*a–c* and with the spaces therebetween. Tubular member further includes spaced slots 138 defined in the lower edge of sidewall 126 and configured to register with a corresponding locking boss 106 in order to secure cover 74 to valve base 70.

FIGS. 7 and 8 illustrate assembled control valve 14 with valve fingers 134*a–c* of cover 74 fitting concentrically about valve fingers 116*a–c* of rotatable element 72. In operation, pressure controller 26 energizes valve motor 78 in order to rotate element 72 clock-wise or counter clock-wise between a fully closed position (FIG. 7), a fully opened position (FIG. 8), and intermediate positions therebetween.

In the fully closed position of FIG. 7, fingers 116*a–c* and 134*a–c* are fully meshed in order to block the respective spaces and ports 122 are in complete registration with recesses 96*a–c*. In this position, all of the air entering inlet tube 130 from source 12 exhausts through ports 122*a–c* and recesses 96*a–c*. In the fully open position of FIG. 8, fingers 116*a–c* and 134*a–c* are in registration so that the spaces therebetween are open, and support bodies 114*a–c* are in registration with and thereby block recesses 96*a–c*. With this orientation, all of the air is exhausted through outlet tube 132 for delivery to the patient.

The intermediate positions between fully opened and fully closed allow respective portions of the inlet air to exhaust through recesses 96*a–c* and through outlet tube 132. In this way, control valve 14 provides more precise control over the pressure delivered to the patient, and provides smoother transition between pressure settings.

In the operation of apparatus 10 during inhalation, it is necessary to provide sufficient pressure to maintain the airway pressure splint in the patient in order to prevent occlusion. For patient comfort, however, it is desirable to lower the pressure to a level as low as possible, including ambient pressure, while still maintaining sufficient pressure to keep the airway open. In order to accomplish these benefits, phase detection circuit 24 detects the inhalation and exhalation phases of the patient's respiration, and provides corresponding outputs to pressure controller 14. In the preferred embodiment, controller 14 controls its output pressure in a predetermined manner correlated with inhalation and exhalation as indicated by the outputs received from circuit 24. More particularly, pressure controller 14 controls the pressure delivered to the patient at a higher level during inhalation and a lower level during exhalation as determined by the settings on DACs 48,50. Typically, the respective inhalation and exhalation pressure levels are prescribed by the patient's physician.

FIGS. 9–11 illustrate control valve **140** which is another embodiment of a control valve for use in place of valve **14**. Valve **140** includes valve body **142** and actuator assembly **144**. Valve body **142** includes external tubular inlet coupler **146** in communication with inlet passage **148**, and further includes exhaust passage **150** and outlet passage **152** having external outlet coupler **154** extending therefrom. As illustrated in FIGS. **10–11**, exhaust and outlet passages **150,152** communicate with inlet passage **148** and extend transversely therefrom, parallel to one another.

Actuator assembly **144** includes valve motor **156**, valve stem **158**, exhaust valve element **160** and outlet valve element **162**. As illustrated in FIGS. **9–11**, motor **156** is coupled to the bottom of body **142** with motor-actuated stem **158** extending upwardly therefrom through, and transverse to, exhaust and outlet passages **150,152**. Valve elements **160,162** present oval-shaped configurations and are coupled with stem **158** for rotation therewith. Element **160** is positioned in exhaust passage **150**, and element **152** is positioned in outlet passage **152**. Valve elements **160,162** function in a manner analogous to conventional butterfly valves. As illustrated, valve elements **160,162** are angularly displaced from one another on stem **158** by about 45°. Valve motor **156** is coupled electrically with pressure controller **26** and receives signals therefrom in the same manner as valve motor **78** or valve **14**.

FIGS. **10** and **11** illustrate control valve **140** in the closed/exhaust position. In this position, exhaust valve element **160** is positioned parallel to the air flow and outlet valve element **162** is positioned so that its edges engage the sidewalls of outlet passage **152** to block all outflow. In other words, all of the inlet air entering through inlet passage **148** would exhaust through exhaust passage **150** and none would be provided through outlet passage **152** to the patient. In the open/outlet position, elements **160** and **162** would be rotated clockwise as viewed from above until the edges of exhaust element **160** engage the walls defining exhaust passage **150**. In this position, outlet element **162** is positioned parallel to the air flow through outlet passage **152**. In this way, no air is exhausted but rather, the full supply is provided through outlet passage **152**.

Motor **156** responds to the signals received from pressure controller **26** in order to position valve **140** in the closed or open positions or any intermediate position therebetween. As with control valve **14**, this arrangement allows smooth controllable transition between the various valve positions.

Having thus described the preferred embodiment of the present invention the following is claimed as new and desired to be secured by Letters Patent:

1. An apparatus for detecting the inhalation and exhalation phases of a respiratory cycle having associated respiratory gas flow, said apparatus comprising:

signal production means for producing first and second signals representative of the respiratory gas flow with said signal production means further including means for delaying one of said signals in time relative to the other of said signals; and said signals having respective amplitudes so that one of said signals presents the greater amplitude during at least a portion of one of the phases and so that the other of said signals presents the greater amplitude during at least a portion of the other of said phases; and

processing means for processing said signals for determining therefrom the occurrence of said respective phases and for producing outputs representative of said phases.

2. The apparatus as set forth in claim **1**, said signal production means including flow sensor means for producing said first signal representative of instantaneous respiratory gas flow and time delay means for producing said second signal delayed in time relative to said first signal.

3. The apparatus as set forth in claim **2**, further including amplitude scaling means for producing said second signal scaled in amplitude relative to said first signal.

4. The apparatus as set forth in claim **3**, said scaling means including means for scaling said amplitude at a first level during one of said phases and means for scaling said amplitude at a second level during the other of said phases.

5. The apparatus as set forth in claim **4**, wherein said means for scaling said amplitudes at a first level and a second level are accessible by a patient.

6. The apparatus as set forth in claim **1**, said processing means including means for comparing the amplitudes of said first and second signals, for producing a first output when said first signal presents a greater amplitude than said second signal, and for producing a second output when said second signal presents a greater amplitude than said first signal.

7. The apparatus as set forth in claim **1**, said first and second signals being electrical signals.

8. The apparatus as set forth in claim **1**, said outputs including electrical signals.

9. An apparatus for facilitating the respiration of a patient having respiratory cycle with associated respiratory gas flow and exhibiting inhalation and exhalation phases, said apparatus comprising:

supply means for supplying a respiratory gas under pressure from a source thereof to a patient;

means for producing first and second signals representative of the respiratory gas flow with said signal production means further including means for delaying one of said signals in time relative to the other of said signals; and said signals having respective amplitudes so that one of said signals presents the greater amplitude during at least a portion of one of the phases and so that the other of said signals presents the greater amplitude during at least a portion of the other of said phases;

processing means for processing said signals for determining therefrom the occurrence of said respective phases and for producing outputs representative of said phases; and

control means coupled with said supply means and said processing means for receiving said outputs and responsive thereto for controlling said respiratory gas pressure to the patient in a predetermined manner correlated with said phases.

10. The apparatus as set forth in claim **9**, said control means including means for controlling said respiratory gas pressure at a first pressure level during the inhalation phase and for controlling said respiratory gas pressure at a second pressure level lower than said first level during the exhalation phase.

11. The apparatus as set forth in claim **10**, said second pressure level including ambient pressure.

12. The apparatus as set forth in claim 10, said second pressure level including a pressure level greater than ambient.

13. The apparatus as set forth in claim 9, said signal production means including flow sensor means for producing said first signal representative of instantaneous respiratory gas flow and time delay means for producing said second signal delayed in time relative to said first signal.

14. The apparatus as set forth in claim 13, further including amplitude scaling means for producing said second signal scaled in amplitude relative to said first signal.

15. The apparatus as set forth in claim 14, said scaling means including means for scaling said amplitude at a first level during one of said phases and means for scaling said amplitude at a second level during the other of said phases.

16. The apparatus as set forth in claim 15, wherein said means for scaling said amplitudes at a first level and a second level are adjustable by a patient.

17. The apparatus as set forth in claim 9, said processing means including means for comparing the amplitudes of said first and second signals, for producing a first output when said first signal presents a greater amplitude than said second signal, and for producing a second output when said second signal presents a greater amplitude than said first signal.

18. The apparatus as set forth in claim 9, said first and second signals being electrical signals.

19. The apparatus as set forth in claim 9, said outputs including electrical signals.

20. A method for detecting the inhalation and exhalation phases of a respiratory cycle having associated respiratory gas flow, said method comprising:

producing first and second signals representative of the respiratory gas flow from a signal production means, delaying one of said signal in time relative to the other of said signals, said signals having respective amplitudes, said first signal presents the greater amplitude during at least a portion of the inhalation phase, said second signal presents the greater amplitude during at least a portion of the exhalation phase; and

processing said signals for determining therefrom the occurrence of said inhalation and exhalation phases and for producing a first output corresponding to the inhalation phase and a second output corresponding to the exhalation phase.

21. The method as set forth in claim 20, wherein said step of producing said first and second signals includes:

using a flow sensor for producing said first signal, said first signal being representative of instantaneous respiratory gas flow; and

using time delay means for producing said second signal delayed in time relative to said first signal.

22. The method as set forth in claim 21, further comprising scaling said second signal in amplitude relative to said first signal.

23. The method as set forth in claim 22, wherein said step of scaling said second signal includes:

using scaling means for scaling the amplitude of an inhalation phase of said second signal to a first level; and

using said scaling means for scaling the amplitude of an exhalation phase of said second signal to a second level.

24. The method as set forth in claim 23, wherein said step of scaling said second signal includes making said scaling means accessible to a patient.

25. The method as set forth in claim 20, wherein said step of processing said signals further includes:

comparing the amplitude of said first signal and second signal;

producing said first output when the amplitude of said first signal is greater than the amplitude of said second signal; and

producing said second output when the amplitude of said second signal is greater than the amplitude of said first signal.

26. The method as set forth in claim 20, wherein said step of producing said first and second signals includes:

producing said first signal as an electrical signal; and

producing said second signal as an electrical signal.

27. The method as set forth in claim 20, wherein said step of processing said signals includes;

producing said first output as an electrical signal; and

producing said second output as an electrical signal.

* * * * *

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United States Patent [19]

Czarnocki

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[45] Date of Patent: Mar. 16, 1993

[54] PRESSURE SENSOR CIRCUIT

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[51] Int. Cl.[5] G01L 19/04

[52] U.S. Cl. 73/708; 73/766; 73/862; 73/623; 324/105; 324/721

[58] Field of Search 73/706, 708, 717, 718, 73/719, 720, 721, 722, 861.47, 862.35, 862.48, 862.58, 862.63, 862.65, 862.67; 338/3, 4; 324/105, 721

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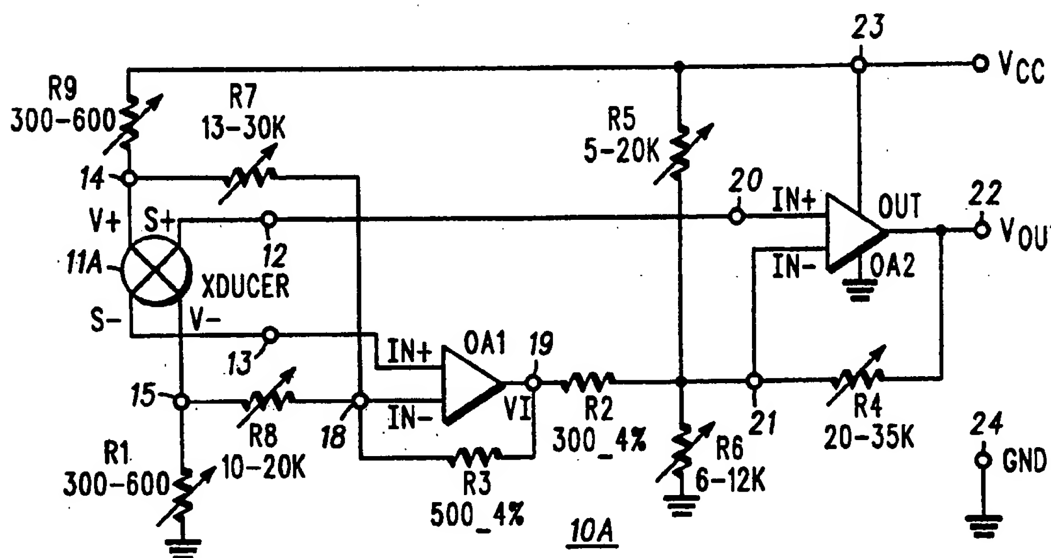
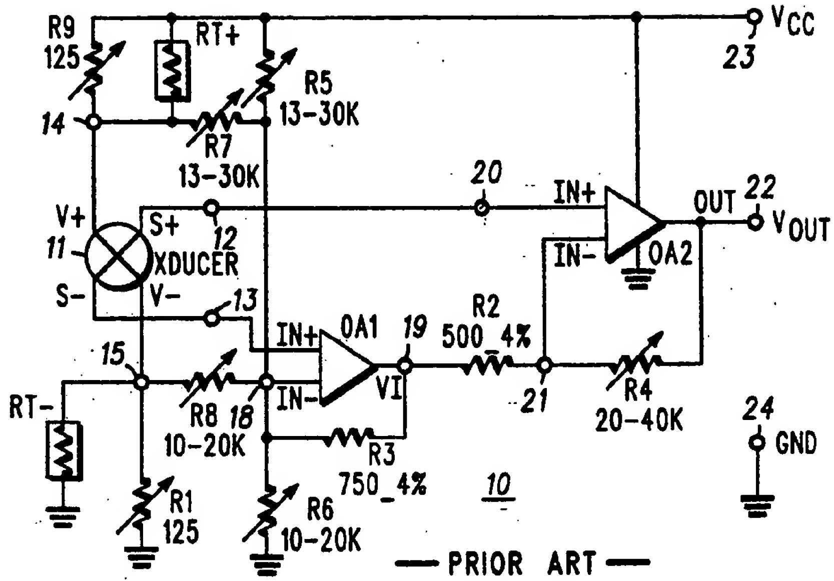
Primary Examiner—Donald O. Woodiel

[57] ABSTRACT

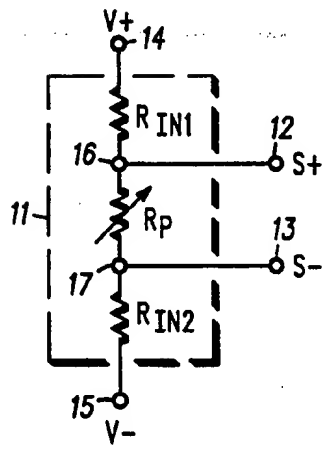
A pressure sensor circuit (10A) is disclosed which preferably utilizes a piezoresistive pressure transducer (11A) having a substantial temperature coefficient of resistance to provide an inherent temperature variation which is used to implement offset temperature compensation for the circuit. Two operational amplifiers (OA1, OA2) are configured along with selectable resistors (R_1, R_9, R_7, R_8, R_5, R_6 and R_4) to implement four adjustments of the circuit (10A) to adjust span (gain), offset and temperature variation of both span and offset to achieve a desired result. All this is achieved while implementing a common mode gain for the circuit (10A) which is less than 5 and preferably no more than 2.

24 Claims, 1 Drawing Sheet



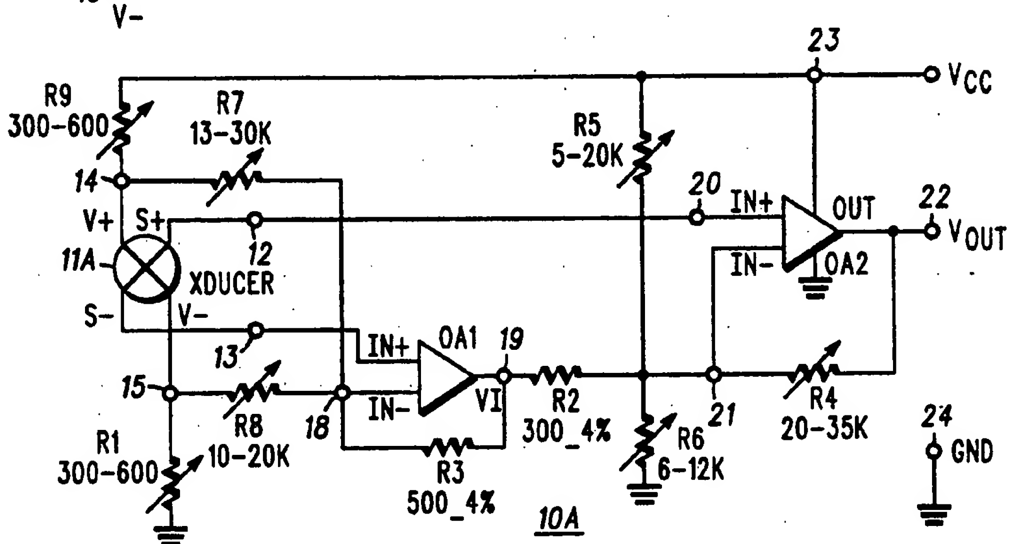


F I G. 1



F I G. 2

F I G. 3



PRESSURE SENSOR CIRCUIT

FIELD OF THE INVENTION

The present invention relates to the field of pressure sensor circuits in which a sensed pressure results in a corresponding electrical signal having a desired sensed pressure versus electrical signal transfer characteristic. More specifically, the present invention relates to a pressure resistive sensor providing a pair of output sensor signals with the difference between these signals related to the magnitude of sensed pressure and an adjustment circuit means for processing these output sensor signals to provide a desired output signal having a desired magnitude variation as a function of sensed pressure and temperature.

BACKGROUND OF THE INVENTION

Previously, pressure resistive sensors have been used to provide a pair of output sensor signals with the difference between these signals being related to the magnitude of sensed pressure. Typically, an adjustment circuit receives these sensor signals and provides four separate adjustments for controlling the variation of a desired pressure related output signal, derived from the pair of sensor signals, with respect to pressure and temperature. For zero applied pressure, the difference between the sensor output signals should be zero and this difference should be maintained despite temperature variations. However, sensor construction results in differences between the sensor output signals which are not due to sensed pressure, and these differences may have both temperature dependent and absolute difference (temperature independent) components. Thus prior circuits have typically provided separate adjustments for the absolute (temperature independent) and temperature dependent variation of the "offset" of the desired output signal due to the existing nonpressure related difference between the sensor output signals. In addition, typically sensor circuits should provide a desired known range for an output signal voltage which corresponds to a desired variation of sensed pressure. This is typically referred to as "span" and generally corresponds to the gain implemented by the adjustment circuit with regard to the output pressure related signal of the circuit and the difference between the two sensor output signals. In addition, this span has its own temperature variation which should be compensated for.

The bottom line is that there are generally four separate adjustments, span, offset, and temperature variation of span and offset, which are implemented by a pressure sensor adjustment circuit. Some prior pressure sensor circuits have implemented all four of these adjustments, but have done so while inherently providing a substantial common mode gain. This "common mode gain" means that even if the difference between the two sensor output signals is related to only pressure, an equal variation of both of these signals will not cancel out, and that will result in a variation of the desired output signal. It has been found that for some pressure sensors long term drift in the same direction for both of the pair of sensor output signals may result. With a high common mode gain, this results in a substantial and undesired variation of the magnitude of the desired output signal such that the output signal no longer has a direct calibrated correspondence to sensed pressure even though all four of the previously mentioned adjustments were made when the sensor circuit was originally calibrated. Some prior sensor circuits have provided a very low common mode gain, but this has been accomplished by the use of more than three operational amplifiers to obtain the needed isolation of various signals. Other sensor circuits have utilized only one operational amplifier, but they have been unable to provide sufficient isolation of sensor signals to perform all four of the needed adjustments while minimizing common mode gain. Typically, such a single operational amplifier circuit is difficult to adjust since several of the needed four adjustments affect common mode unbalance.

A sensor circuit using two operational amplifiers has been provided and is shown in FIG. 1. This prior art circuit is capable of implementing all four needed adjustments. However, this circuit has a common mode gain of approximately 20. For small long term common mode drift of the pair of sensor output signals, this resulted in an unacceptable variation of the output signal of the sensor circuit. While various passivations for the pressure sensor itself tend to minimize the amount of long term drift, this does not eliminate the problem to a sufficient extent.

OBJECTS OF THE INVENTION

An object of the present invention is to provide an improved pressure sensor circuit which overcomes the above noted disadvantages of prior pressure sensor circuits.

A more specific object of the present invention is to provide an improved pressure sensor circuit having a common mode gain of less than five while minimizing the cost of such a pressure sensor circuit.

An additional object of the present invention is to provide an improved pressure sensor circuit having a specific circuit configuration which utilizes only two operational amplifiers and provides for implementing all four of the needed signal adjustments while minimizing common mode gain.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention can be better understood by reference to the drawings in which:

FIG. 1 is a schematic diagram of a prior art pressure sensor circuit;

FIG. 2 is a schematic diagram of an equivalent electrical circuit for a pressure sensing element; and

FIG. 3 is a schematic diagram of a pressure sensor circuit constructed in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to the prior art circuit configuration shown in FIG. 1, a pressure sensor circuit 10 is illustrated. The circuit includes a pressure transducer, or pressure sensing element, 11 for sensing pressure and in response thereto providing a first sensor voltage signal S+ and a second voltage sensor signal S− at first and second output terminals 12 and 13 of the sensor 11. The differential voltage between the sensor signals S+ and S− is related to sensed pressure.

Preferably, the sensor 11 is a piezoresistive pressure sensor in which an equivalent pressure variable resistor R_p varies in accordance with sensed pressure. FIG. 2 illustrates a typical equivalent circuit for such a pressure sensor 11 with the pressure variable resistor R_p being connected in series with non-pressure variable resistors

R_{IN1} and R_{IN2} between terminals 14 and 15, separate from the terminals 12 and 13, across which a differential applied voltage of V+"V− is applied. While a series equivalent circuit for the sensor 11 is shown in FIG. 2, another way of schematically illustrating the equivalent circuit of the sensor 11 would be to illustrate a bridge configuration. In such a bridge circuit a pair of pressure independent resistors are connected with a pair of pressure variable resistors with a voltage differential of V+ to V− being applied across the bridge and the bridge providing a differential output of S+−S− across output terminals 12 and 13. Regardless of which equivalent circuit is utilized to depict the pressure sensor 11, the operation of the circuit 10 is identical.

Referring again to FIG. 1, the sensor voltage signal S− is directly connected to a non-inverting input IN+ of a first operational amplifier OA1. The terminal 15 at which the applied voltage V− is provided at is connected through an adjustable resistor R_8 to a terminal 18 which is an inverting input IN− of the operational amplifier OA1. The output of the first operation amplifier is provided at a terminal 19 which is connected through a negative feedback resistor R_3 to the terminal 18 and through a resistor R_2 to a terminal 21. The signal at the terminal 19 is designated as VI to indicate that this is an intermediate voltage signal provided at this terminal which is related to the sensor output voltage signal S−. The terminal 18 is connected to ground through a variable resistor R_6 and is connected to a positive source of fixed voltage potential V_{cc} at a terminal 23 through a variable resistor R_5. The terminal 15 is connected to ground through the parallel combination of an adjustable resistor R_1 and a negative temperature coefficient thermistor RT−. The terminal 14 is connected to the terminal 18 through a variable resistor R_7 and is connected to the terminal 23 through the parallel combination of a variable resistor R_9 and a thermistor RT+.

In circuit 10, the sensor output signal S+ at the terminal 12 is connected to a terminal 20 corresponding to the non-inverting input IN+ of a second operational amplifier OA2 which has its inverting input IN− directly connected to the terminal 21. The output of the second operational amplifier OA2 is provided at an output terminal 22 which is connected by means of a variable feedback resistor R_4 to the terminal 21. The signal at the terminal 22 is designated as V_{out} and has a desired pressure and temperature variation characteristic. The sensor 11 shown in FIG. 1 is a piezoresistive sensor having a temperature coefficient of resistance for its pressure variable and nonpressure variable resistors of less than 0.30% per degree C., and in actuality having a temperature coefficient resistance of 0.27% per degree C. FIG. 1 indicates typical values, in ohms, for the resistors of circuit 10. The alphabetic designation K for a resistor value indicates a multiplier of 1,000. The operation of the prior art circuit 10 will now be discussed.

The circuit 10 implements all four of the needed signal adjustments such that the output signal V_{out} has a desired pressure and temperature variation. However, this circuit configuration implements a common mode gain of 20 and therefore is subject to errors due to common mode variation of the pair of sensor output signals S+ and S−. The present invention will reconfigure the circuit configuration shown in FIG. 1 so as to overcome this problem.

For the circuit 10, the resistors R_9 and R_1 are utilized to selectively adjust the temperature coefficient f the span (gain) of the circuit 10. One of the resistors R_7 and

R_8 is used to adjust the temperature coefficient of the offset for the output signal V_{out} due to any non-pressure related difference between the signals S+ and S−. This is referred to as the temperature coefficient offset adjustment. The variable resistor R_4 is utilized to adjust the absolute value of the span or gain of the circuit 10. The resistors R_5 and R_6 are utilized to adjust the absolute value of the offset of this circuit.

While the circuit configuration shown in FIG. 1 performed satisfactorily in the absence of common mode drift for the sensor 11, the circuit did not function as well when such drift was present because it implemented a common mode gain of approximately 20. It can be shown that the transfer function for the circuit 10 can be approximately represented by the equation:

$$V_{out} = \frac{R_4}{R_2}(S^+ - S^-) + S^+ - \frac{R_4}{R_2}\left(\frac{R_3}{R_5} + \frac{R_3}{R_6} + \frac{R_3}{R_7} + \frac{R_3}{R_8}\right)S^- + \frac{R_4}{R_2}\left(\frac{R_3}{R_7}V^+ + \frac{R_3}{R_8}V^-\right) \tag{1}$$

For a common mode gain of zero, the voltage V_{out} should only be a function of the difference between S+ and S−, since any equal shift of S+ and S− in the same direction should cancel out. Equation 1 illustrates that for circuit 10 to achieve a common mode voltage gain of zero, which is a desired condition, the following equality must be achieved since V+ and V− do not change significantly for expected variations of S+ and S−:

$$1 = \frac{R_4}{R_2}\left(\frac{R_3}{R_5} + \frac{R_3}{R_6} + \frac{R_3}{R_7} + \frac{R_3}{R_8}\right) \tag{2}$$

However, the condition of equation 2 is not feasible to achieve since the ratio of resistors R_4 to R_2 must be substantial to achieve a reasonable gain for the circuit and the right side of equation 2 must be approximately 20 in order to allow proper adjustment for offset for the signal V_{out}. In addition, another shortcoming of the prior art circuit 10 is that it requires the use of thermistors RT+ and RT−. These components represent additional circuit components and therefore represent an additional cost in parts and assembly.

To overcome the deficiencies of the prior art circuit 10 shown in FIG. 1, an improved sensor circuit 10A as shown in FIG. 3 was implemented. The improved circuit configuration 10A utilizes a piezoresistive pressure transducer 11A wherein now the temperature coefficient of resistance of the resistors of this transducer is substantial. This substantial coefficient is more than 0.30% per degree C. and in actuality is 0.35% per degree C. indicating a 25% higher temperature coefficient of resistance than the transducer 11. The piezoresistive transducer 11A is implemented by using different doping levels of boron in the manufacture of the pressure transducer. It should be noted that in both of the transducers 11 and 11A a typical value for the pressure variable resistor R_p is somewhere between 3 and 10 ohms over the range of pressures being measured whereas the fixed resistors R_{IN1} and R_{IN2} are both approximately

220 ohms. This therefore indicates the need for a substantial gain which must be implemented by the remaining circuitry to produce a measurable variation in the output signal V_{out} as a function of pressure.

In addition to the circuit 10A utilizing the transducer 11A rather than the transducer 11, there are no thermistors provided in parallel with resistors R_1 and R_9 as shown in FIG. 3. In addition, and very significantly, the offset adjustment resistors R_5 and R_6 are now no longer connected to the terminal 18 but are now connected to the terminal 21. Except for these changes, and the fact that the resistors shown in FIG. 3 now have somewhat different nominal values as indicated in FIG. 3, the circuitry of the circuit 10A is identical to that of the circuit 10 shown in FIG. 1. However, now the transfer characteristic for the voltage V_{out} for the circuit 10A is approximately expressed by the following equation 3 which is:

$$V_{out} = \frac{R_4}{R_2}(S^+ - S^-) - \frac{R_4}{R_5}V_{CC} + \frac{R_4}{R_2}\left(\frac{R_3}{R_7}V^+ + \frac{R_3}{R_8}V^-\right) + \left(1 + \frac{R_4}{R_5} + \frac{R_4}{R_6}\right)S^+ - \frac{R_4}{R_2}\left(\frac{R_3}{R_7} + \frac{R_3}{R_8}\right)S^- \quad (3)$$

Because of this new transfer function for the circuit 10A, as expressed above, in order to implement a common mode gain of zero, the condition of the following equation must be met since V+ and V− do not change significantly for variations of S+ and S−:

$$\left(1 + \frac{R_4}{R_5} + \frac{R_4}{R_6}\right) = \frac{R_4}{R_2}\left(\frac{R_3}{R_7} + \frac{R_3}{R_8}\right) \quad (4)$$

By choice of the magnitude of resistors R_2 and R_3 for typical values of the other resistors, this condition can be met to a very close degree such that a common mode gain of less than 5 and preferably no more than 2, and in fact of no more than 1.5, can be readily implemented. This occurs because the resistors R_5 and R_6, because of their present positioning, now provide an effect for the amplification of the signal S+ with respect to the transfer characteristic so as to potentially cancel the effect of resistors R_4, R_2, R_3, R_7 and R_8 with respect to the amplification of the signal S−. Thus providing the absolute offset adjustment resistors R_5 and R_6 at an input of OA2, while providing the additional temperature offset adjustment resistors R_7 and R_8 at an input of OA1 has created an improved circuit. In addition, because the transducer 11A is utilized, the temperature variation produced by the transducer 11A itself is utilized for adjustment of the temperature coefficient of offset and span by the resistors R_1 and R_9 and R_7 and R_8. This eliminates the use of additional thermistor components and therefore reduces the cost of the circuit 10A.

The method for adjusting the resistors in the circuit 10A so as to achieve the four necessary adjustments for a pressure sensor circuit is as follows.

For the circuit 10A in FIG. 3, the first adjustment to be made is for the temperature coefficient of the span (or gain) of the circuit. For this adjustment resistors R_1 and R_9 are adjusted to obtain a zero temperature variation of the output voltage gain for V_{out} at two different temperatures. In practice, temperatures of 25° C. and 85° C. were selected to achieve this adjustment. Thus for a known change in pressure the change in V_{out} is measured at one temperature, the temperature is changed, and one of the resistors R_9 or R_1 is adjusted to achieve the same V_{out} magnitude change for the same pressure change. Subsequently, the span of the circuit 10A is adjusted at a fixed temperature by adjusting the magnitude of the resistor R_4 to get a desired change in output voltage versus a known change in pressure. The span adjustment assures that a proper difference or range between maximum and minimum values of the signal V_{out} will occur for the expected range of pressures to be sensed. In other words a proper ΔV_{out} will result from the expected Δ pressure range.

The third circuit adjustment to be implemented is for the temperature coefficient of offset and this is achieved by adjusting one of the resistors R_7 or R_8. These resistors are adjusted such that for zero pressure at two different temperatures, such as 25° C. and 85° C., there will be zero variation of the output voltage V_{out}.

The fourth adjustment to be implemented is the offset adjustment for the circuit 10A and this is achieved by adjusting one of the resistors R_5 or R_6. The adjusted resistor is adjusted such that for zero sensed pressure a desired absolute magnitude of the output signal V_{out} is achieved. After initially implementing the above four adjustments, it was found that there may be required an additional minor adjustment of the gain (span) by adjusting the magnitude of the resistor R_4 and then an additional minor adjustment of the offset by adjusting one of the resistors R_5 or R_6. With the adjustments made in the above noted sequence, the circuit 10A has been found to implement a desired pressure sensor circuit having a common mode gain of no more than two while utilizing only two operational amplifiers and having fewer components since a transducer having a substantial temperature coefficient of resistance has been utilized thus eliminating the need for thermistors as part of the circuit.

While I have shown and described specific embodiments of this invention, further modifications and improvements will occur to those skilled in the art. All such modifications, such as providing a current output signal rather than a voltage output signal V_{out}, which retain the basic underlying principles disclosed and claimed herein are within the scope of this invention.

I claim:

1. A pressure sensor circuit comprising:

a pressure resistive sensor means for sensing pressure and in response thereto providing first and second sensor signals at first and second sensor output terminals of said sensor means, the differential signal between said output terminals related to the magnitude of sensed pressure, and

adjustment circuit means for receiving said first and second sensor signals and providing in response thereto a pressure related output signal having a desired magnitude variation characteristic as a function of pressure and temperature,

said adjustment circuit means including resistive means for adjusting the span of said desired output signal as a function of pressure, the absolute offset of said output signal with respect to said first and second sensor signals, and the temperature coefficient of variation of both said offset and said span, said adjustment circuit means including at least and

no more than two operational amplifiers with one of said first and second sensors signals coupled to an input of a first one of said two operational amplifiers which provides an output coupled to an input of a second one of said two operational amplifiers which provides an output corresponding to said pressure related output signal, said two operational amplifiers providing a common mode gain for said desired output signal with respect to said first and second sensor signals of less than five.

2. A pressure sensor circuit according to claim 1 wherein said common mode gain is no more than 2.

3. A pressure sensor circuit according to claim 1 wherein said adjustment circuit means includes offset adjustment resistors connected to one input terminal of one operational amplifier which receives one of said sensor signals at another input terminal of said one operational amplifier and provides at an output terminal of said one operational amplifier said desired pressure variable output signal.

4. A pressure sensor circuit according to claim 3 wherein said adjustment circuit means includes another operational amplifier which receives as an input and amplifies another of said sensor signals and has its output coupled to said one input terminal of said one operational amplifier.

5. A pressure sensor circuit according to claim 4 wherein said pressure resistive sensor means comprises a piezoresistive pressure sensor.

6. A pressure sensor circuit according to claim 5 wherein a selectable feedback resistance is connected from the output of said one operational amplifier to said one input terminal thereof for controlling the gain of said one operational amplifier, wherein offset adjustment resistor means, which comprises said offset adjustment resistors, is connected to said one input terminal of said one operational amplifier for resistively selecting a desired offset adjustment for said desired pressure related output signal with respect to said first and second sensor signals, and wherein additional adjustment resistors are connected to one of the inputs of said another operational amplifier for implementing an additional offset adjustment.

7. A pressure sensor circuit comprising:

a pressure resistive sensor means for sensing pressure and in response thereto providing first and second sensor voltage signals at first and second sensor output terminals of said sensor means, the differential voltage between said output terminals related to the magnitude of sensed pressure; and

adjustment circuit means for receiving said first and second sensor voltage signals and providing in response thereto a pressure related output signal having a desired voltage variation characteristic as a function of pressure and temperature,

said adjustment circuit means including resistive means for adjusting the span of said desired output signal as a function of pressure, the absolute offset of said output signal with respect to said first and second sensor signals, and the temperature coefficient of variation of both said offset and said span, said adjustment circuit means including at least and no more than two operational amplifiers with one of said first and second sensors signals coupled to an input of a first one of said two operational amplifiers which provides an output coupled to an input of a second one of said two operational amplifiers which provides an output corresponding to said pressure related output signal, said two operational amplifiers providing a common mode gain for said desired output signal with respect to said first and second sensor signals of less than five.

8. A pressure sensor circuit according to claim 7 wherein said common mode gain is no more than 2.

9. A pressure sensor circuit according to claim 8 wherein said adjustment circuit means includes offset adjustment resistors connected to one input terminal of one operational amplifier which receives one of said sensor voltage signals at another input terminal of said one operational amplifier and provides at an output terminal of said one operational amplifier said desired pressure variable output signal.

10. A pressure sensor circuit according to claim 9 wherein said adjustment circuit means includes another operational amplifier which receives as an input and amplifies another of said sensor voltage signals and has its output coupled to said one input terminal of said one operational amplifier.

11. A pressure sensor circuit according to claim 10 wherein said pressure resistive sensor means comprises a piezoresistive pressure sensor.

12. A pressure sensor circuit according to claim 11 wherein a selectable feedback resistance is connected from the output of said one operational amplifier to said one input terminal thereof for controlling the gain of said operational amplifier, wherein offset adjustment resistor means, which comprises said offset adjustment resistors, is connected to said one input terminal of said one operational amplifier for resistively selecting a desired offset adjustment for said desired pressure related output signal with respect to said first and second sensor voltage signals, and wherein additional adjustment resistors are connected to one of the inputs of said another operational amplifier for implementing an additional offset adjustment.

13. A pressure sensor circuit comprising:

a pressure resistive sensor means for sensing pressure and in response thereto providing first and second sensor voltage signals at first and second output terminals of said sensor means, the differential voltage between said first and second sensor voltage signals being related to sensed pressure, and

adjustment circuit means for receiving said first and second sensor voltage signals and providing in response thereto a desired pressure related output signal having a desired voltage variation characteristic as a function of pressure and temperature,

said adjustment circuit means including first and second operational amplifiers each having first and second input terminals of opposite polarity and an output terminal, said first operational amplifier receiving said second sensor voltage signal at its first input terminal and having temperature compensation adjustment resistors connected to its second input terminal for adjusting the temperature variation characteristic of said output signal, said second operational amplifier receiving said first sensor voltage signal at its first input terminal and having its second input terminal coupled to the output of said first operational amplifier for receiving the output thereof, said second operational amplifier providing at its output said desired pressure related output signal and having a selectable feedback resistance connected from its output to its second input terminal for controlling the gain of said second operational amplifier, and offset adjust-

ment resistor means connected to said second input terminal of said second operational amplifier for resistively selecting a desired offset adjustment for said pressure related output signal with respect to said first and second sensor voltage signals.

14. A pressure sensor circuit according to claim 13 wherein said pressure resistive sensor means comprises a piezoresistive pressure sensor.

15. A pressure sensor circuit according to claim 14 wherein said piezoresistive pressure sensor has positive and negative applied voltage input terminals, separate from said first and second sensor output terminals, for having a voltage applied thereacross, said piezoresistive sensor effectively including at least one pressure variable resistance and a pair of non-pressure variable resistances which determine said sensor voltage signals.

16. A pressure sensor circuit according to claim 15 wherein said piezoresistive sensor comprises a piezoresistive sensor having a temperature coefficient of resistance for its pressure variable and non-pressure variable resistances of more than 0.30% per degree C. as opposed to a piezoresistive sensor having a temperature coefficient of resistance of less than 0.30% per degree C.

17. A pressure sensor circuit according to claim 16 which includes a first selectable non-temperature variable resistance connected between a voltage potential and said first sensor applied voltage input terminal and a second non-temperature variable selectable resistor connected between another different voltage potential and said second sensor applied voltage input terminal.

18. A pressure sensor circuit according to claim 17 wherein said another different voltage potential corresponds to ground potential.

19. A pressure sensor circuit according to claim 17 which includes a pair of selectable resistors a second one of which is connected between said second sensor applied voltage input terminal and said second input terminal of said first operational amplifier and a first one of said pair of selectable resistors connected between said first sensor applied voltage input terminal and said second input terminal of said first operational amplifier, said pair of selectable resistors determining the temperature coefficient of the offset of said desired pressure related output signal with respect to said first and second sensor voltage signals.

20. A pressure sensor circuit according to claim 19 wherein said offset adjustment resistor means includes a first offset adjustment resistor connected between ground potential and said second input terminal of said second operational amplifier and a second offset adjustment resistor connected between a source of voltage potential other than ground potential and said second input terminal of said second operational amplifier, wherein said offset adjustment resistors determine a desired absolute offset for said desired pressure related output signal with respect to said first and second sensor voltage signals.

21. A pressure sensor circuit according to claim 20 wherein a resistor couples the output of said first operational amplifier to the second input terminal of said second operational amplifier, said feedback resistor and said coupling resistor determining the gain of said second operational amplifier.

22. A pressure sensor circuit according to claim 21 wherein said second input terminal of said second operational amplifier is an inverted input terminal.

23. A pressure sensor circuit according to claim 13 wherein said second input terminal of said second operational amplifier is an inverted input terminal.

24. A pressure sensor circuit according to claim 13 wherein said offset adjustment resistor means includes a first offset adjustment resistor connected between one voltage potential and said second input terminal of said second operational amplifier and a second offset adjustment resistor connected between another voltage potential other than said one voltage potential and said second input terminal of said second operational amplifier, wherein said offset adjustment resistors determine a desired absolute offset for said desired pressure related output signal with respect to said first and second sensor voltage signals.

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